A Novel G-APD Based Camera for Imaging Air Cherenkov Telescopes: Concept, Realization and First Tests

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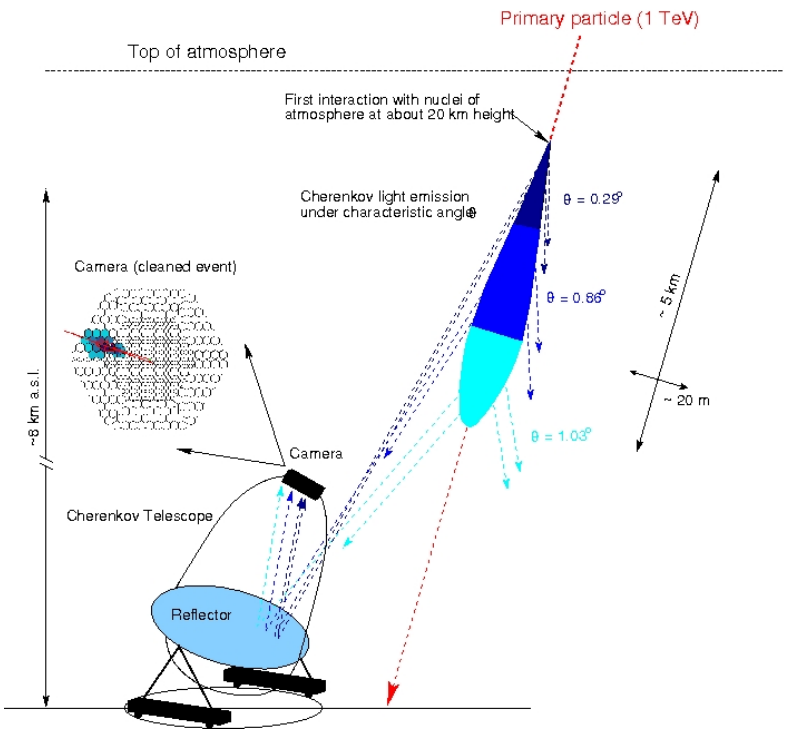
Introduction and Motivation

Imaging Air Cherenkov Telescopes (IACTs)

Gamma rays hitting the Earth's atmosphere produce an air shower. The Cherenkov light emitted by the charged particles in the air shower is measured with IACTs.



Imaging Technique

Shower Image Characteristics:

- Time distribution of Cherenkov photons: a few ns
- γ-ray energy is proportional to the number of produced Cherenkov photons.

Photo Detector Requirements:

- Fast photo detectors
- high photon detection efficiency
- Robust (no ageing, background light, weather)
- High dynamic range (> 1000) desirable

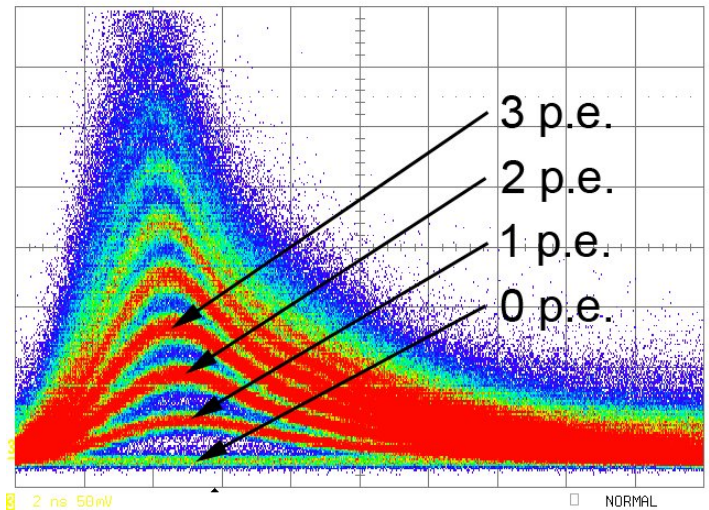
Geiger-mode Avalanche Photodiodes (G-APD)

Advantages:

- Low bias voltage (< 100 V)
- High gain ($10^5 - 10^7$)
- Not damaged by bright light
- Light and robust
- High PDE (30-50%)
- No time-jitter (< 100 ps)
- Single photon resolution
- Independence of angle of incidence
- Insensitive to magnetic field

Disadvantages:

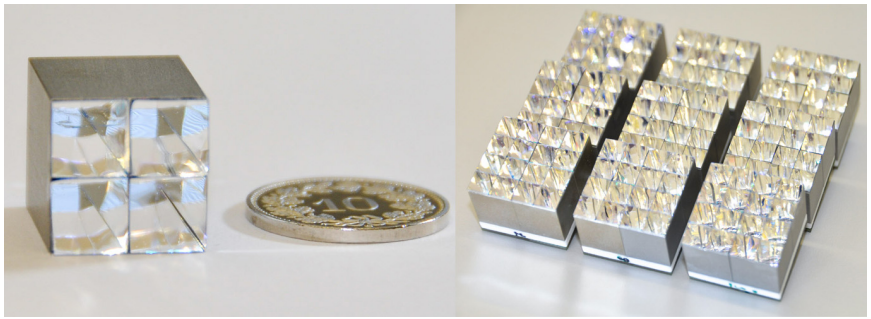
- Temperature dependence
- Optical crosstalk
- Dynamic range smaller than PMT
- No long term experience



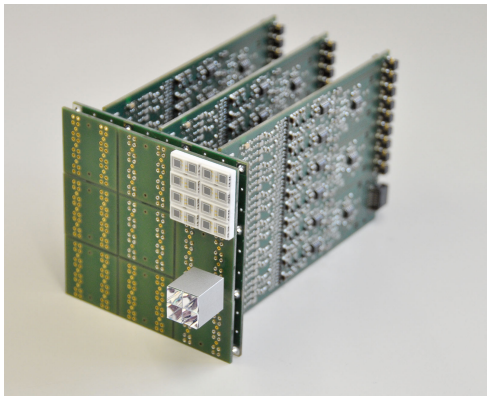
Hamamatsu MPPC S10362-33-50C

G-APD Camera Prototype Module

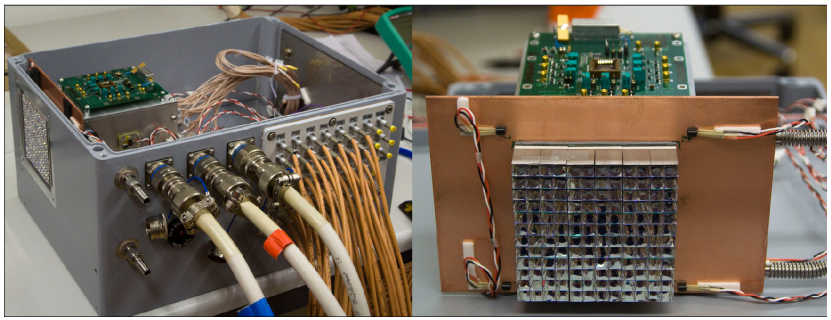
Setup of the Prototype Module



Each G-APD has 1 Winston Cone (light collector). 4 G-APDs together form one pixel, corresponding to one readout channel

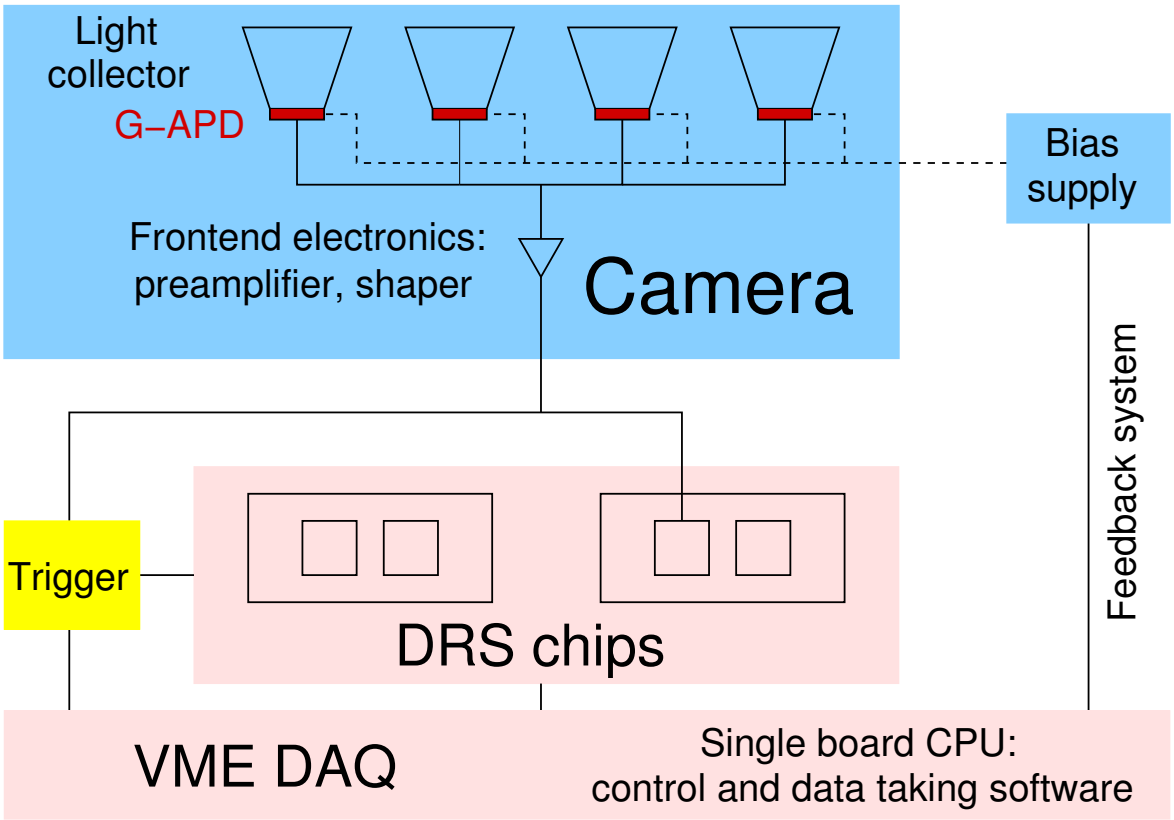


The G-APDs are connected to 3 preamplifier boards (preamplification, bias voltage distribution, summation of each 4 G-APD signals to one readout pixel)



Cooling plate and weather proof camera box

Readout and Trigger System of Prototype



Data Acquisition (DAQ):

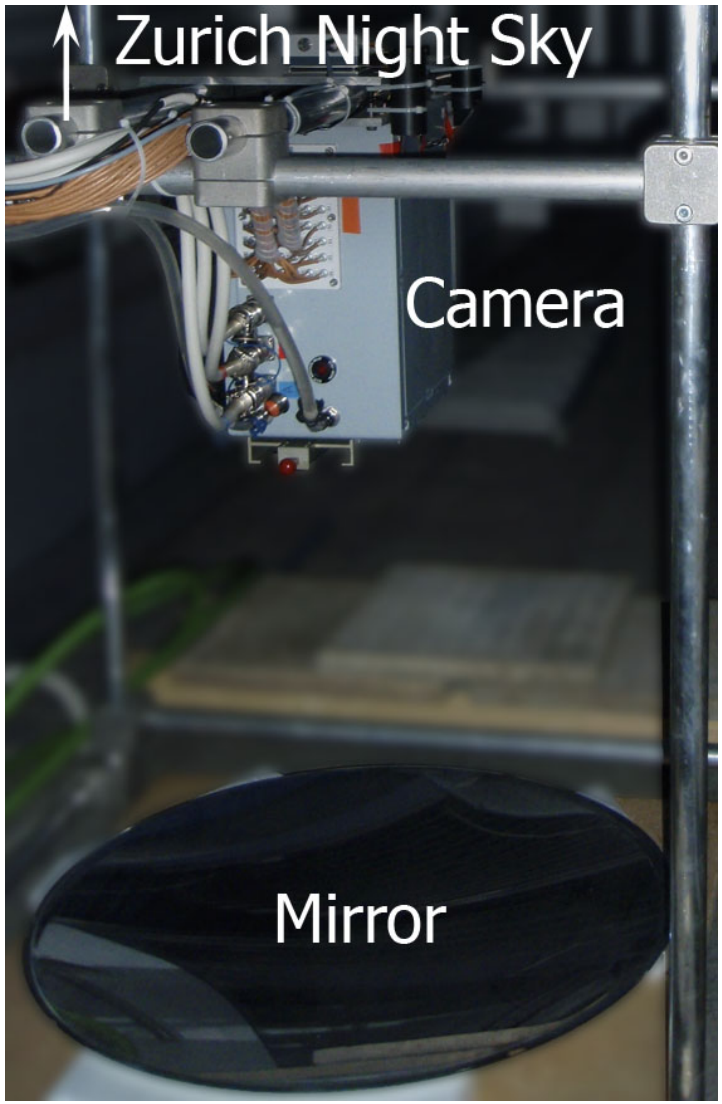
- Domino Ring Sampling chip (DRS2)
- Anal. pipeline: 1024 cells
- 2 GHz, possible rates at $0.5 - 2$ GHz
- Multiplexed 12 bit ADC
- VME housing and CPU

Trigger System:

- Majority coincidence of 16 innermost pixels
  e.g. 3 or 4 out of 16.
- VME boards and scaler

Measurements with Prototype

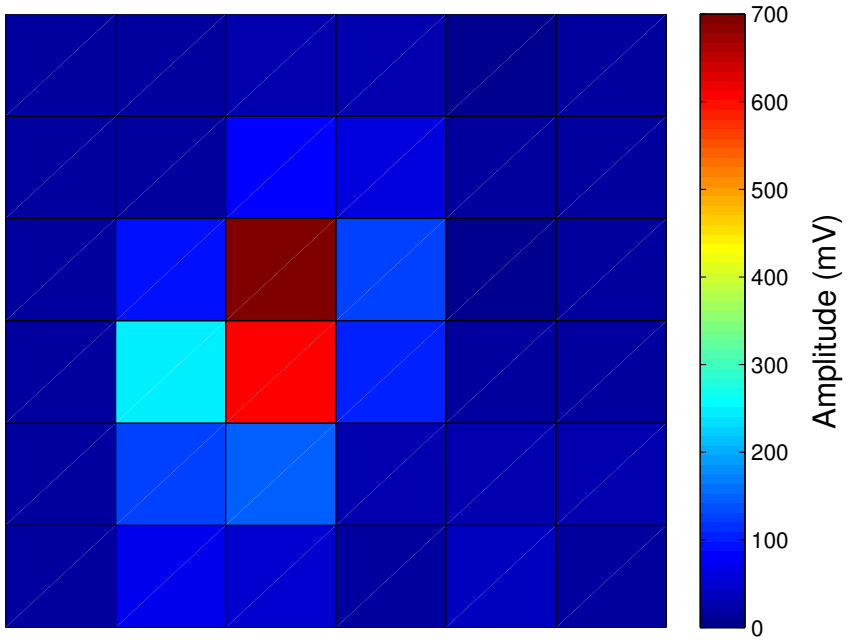
"Telescope" Setup at ETH Zurich



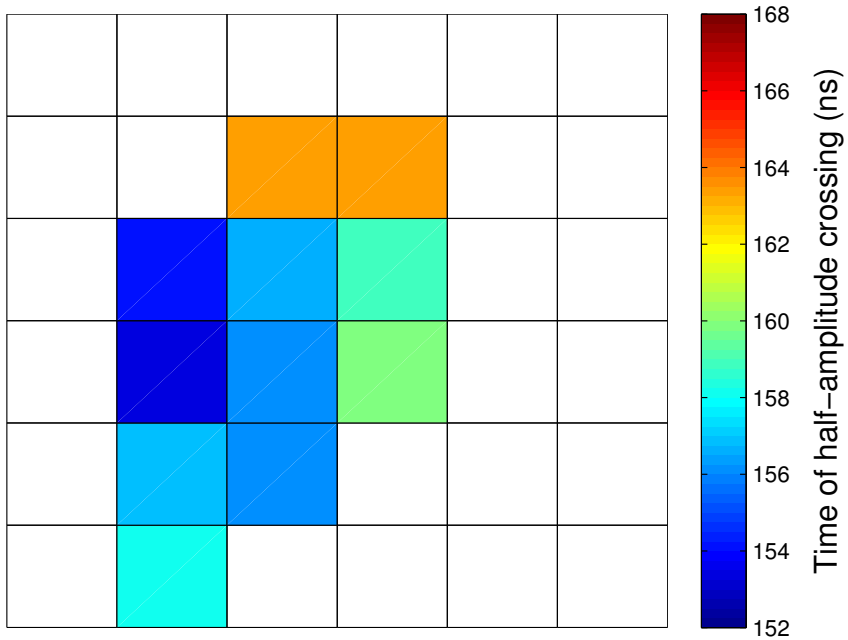
- 80 cm mirror with the prototype camera installed at its focal point.
- High night sky background (moon, streetlights, Zurich): $\sim 300\,\mathrm{MHz}$ / G-APD (i.e. $1.2\,\mathrm{GHz}$ / pixel)
- Temperatur stabilized (different runs with temperatures between 8-22°C).
- Changing weather conditions (outdoor temperature, humidity)

Recorded Cosmic Air Showers - Run# 206, Event# 14

Max. Amplitude

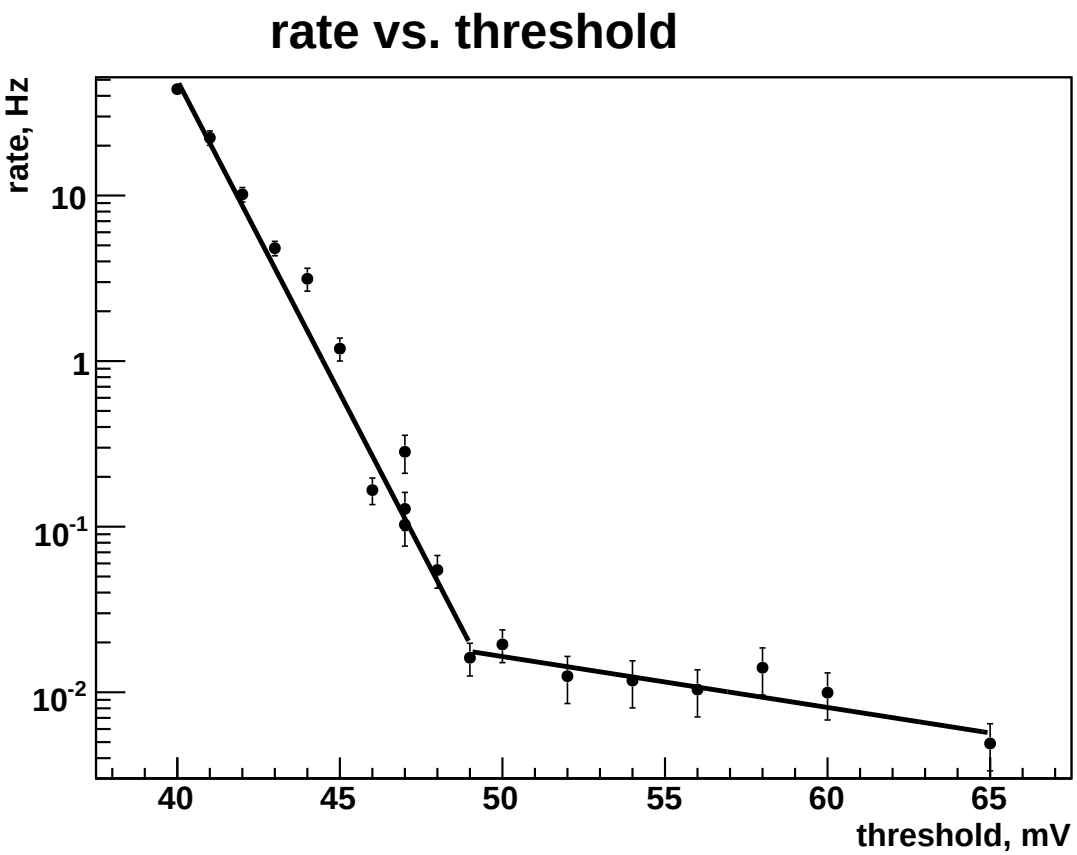


Timing



- Arrival time defined as time of half amplitude crossing
- Only pixels with amplitudes larger 60 mV considered for time calculation

Rate Scan (night of September 23)



- Thresholds for individual pixels varied
- Majority trigger: 3 out of 16

- Rate corrected for deadtime of readout system (here 25 ms)
- Correlation with external PMTs cross-checked ($\pm$ 7 m from camera)

Summary

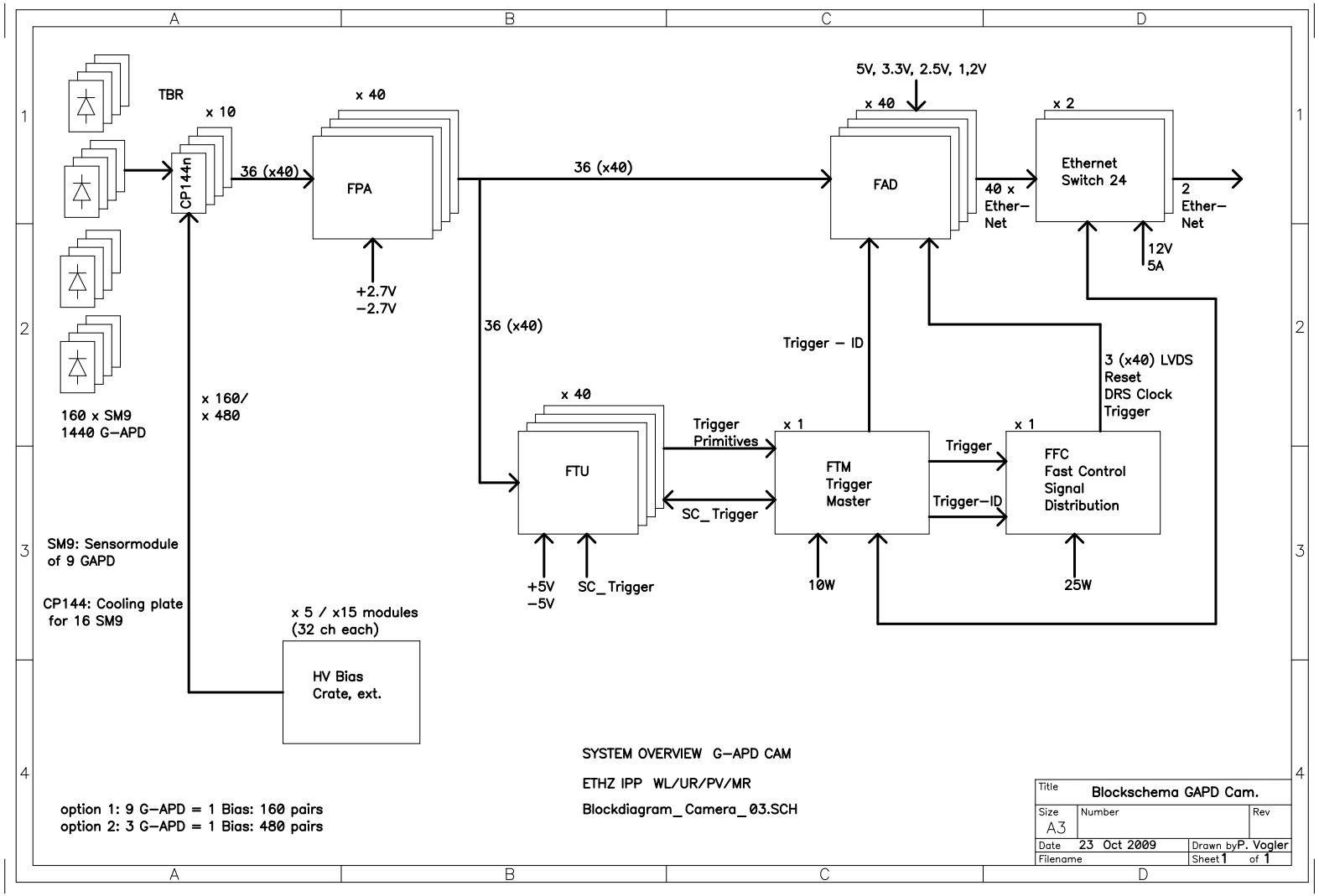
- A 36 pixel (144 G-APDs) prototype G-APD camera to measure Cherenkov light images from extended air showers has been constructed and commissioned
- Operation at room temperatures ($8° - 22°$C) and high night sky background (1.2 GHz/pixel) possible
- First air showers have been recorded (self- and externally triggered)
- A rate scan (rate vs. trigger threshold) shows the expected behaviour: a steep NSB spectrum, going over in a flat spectrum originating from cosmic ray shower triggers

Outlook

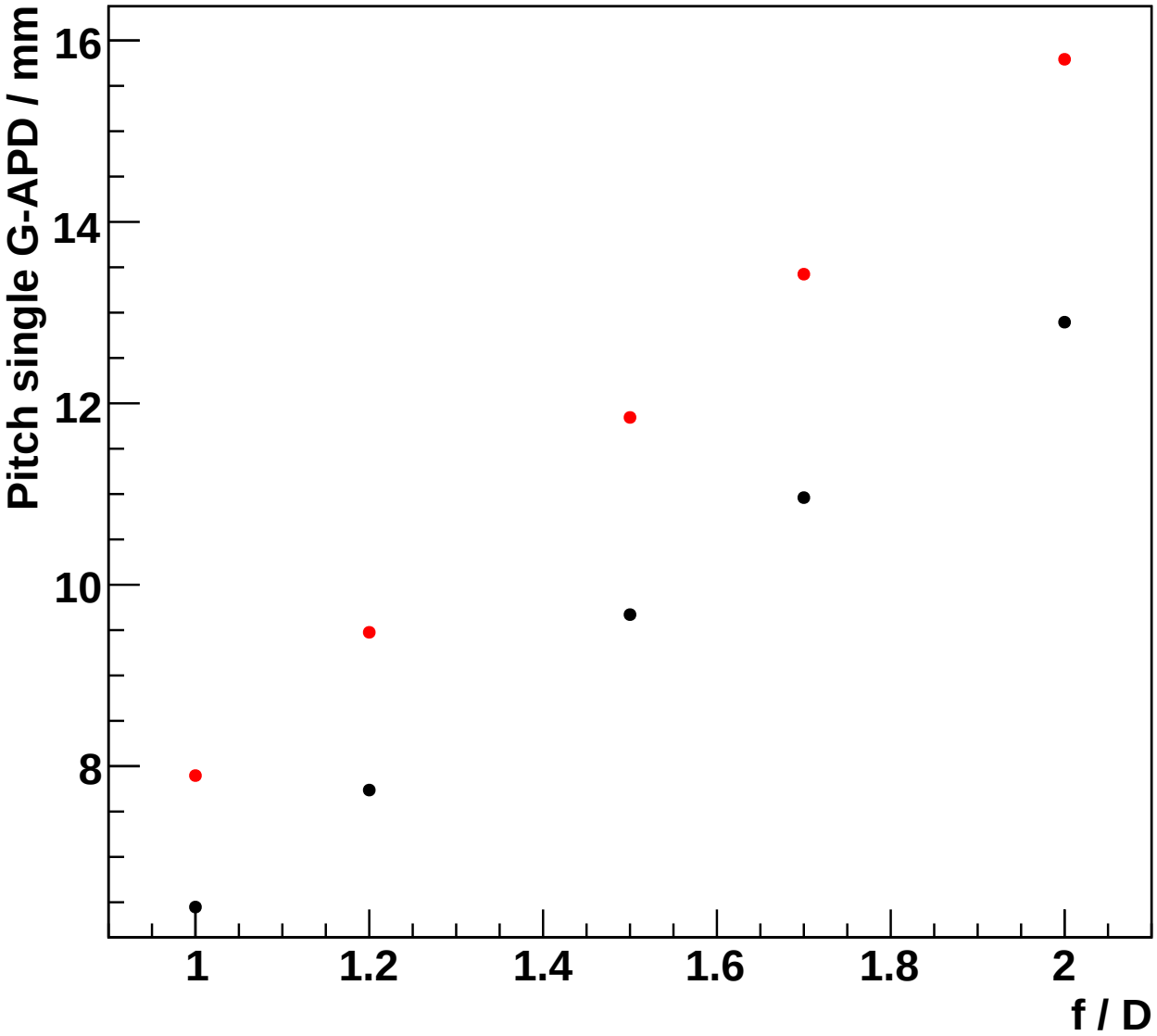
- We started to investigate and develop a camera with a field of view between 4°–5°
- Optimized for a 5 m telescope (e.g. CT3, La Palma, Spain)
- Investigation of solid Winston cones
  ⇒ Larger opening angles possible
  ⇒ Single G-APD readout
- Modular design: Preamplifier boards - trigger boards - DAQ boards stackable. Data transfer from camera to counting house over ethernet
- Readout based on DRS4 chip

- Physics goal:
  - Observation of bright VHE γ-ray sources
  - Blazar monitoring

Backup: Readout Electronics (Block Diagram)

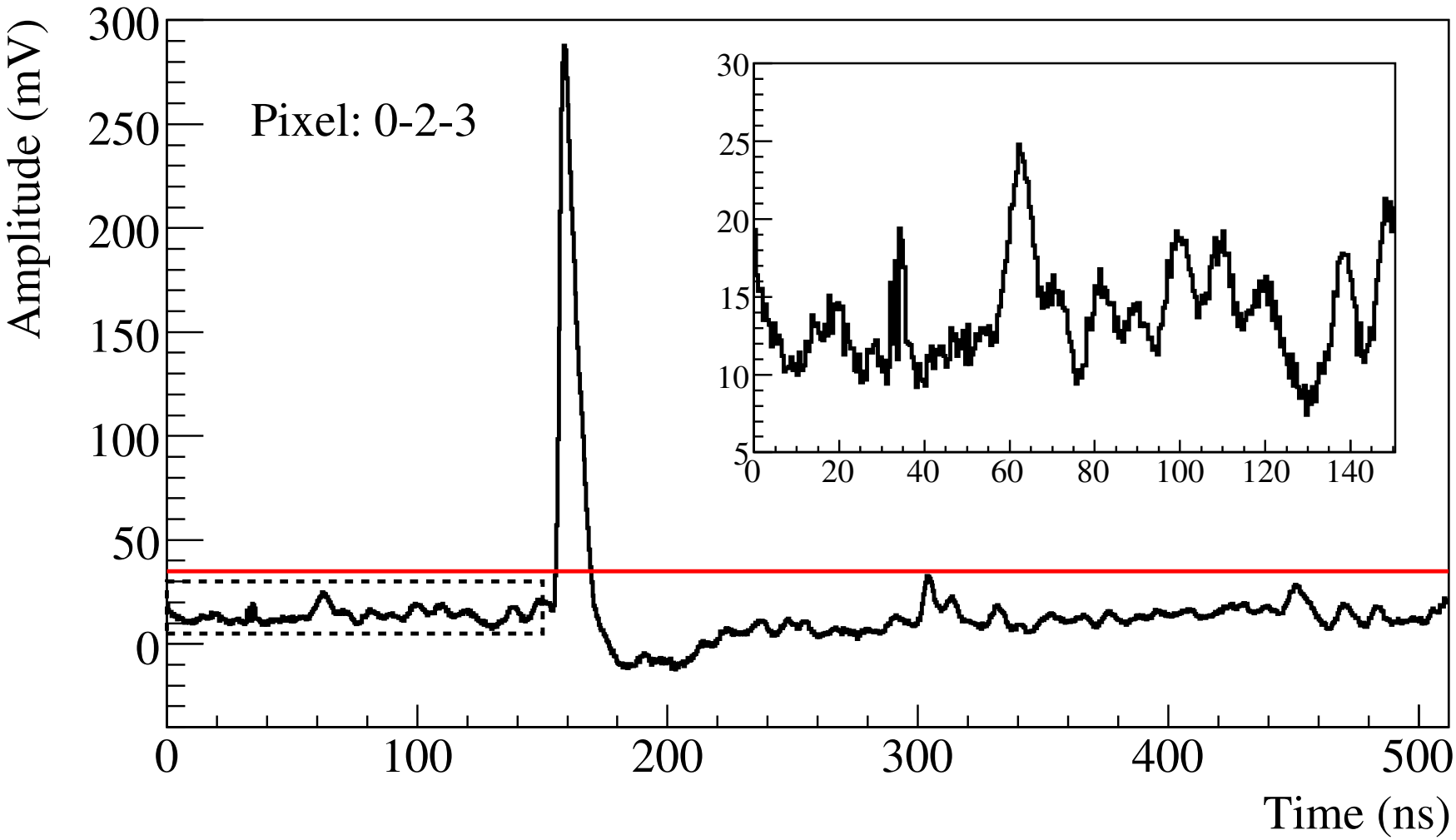


Backup: Winston Cones (Simulations)

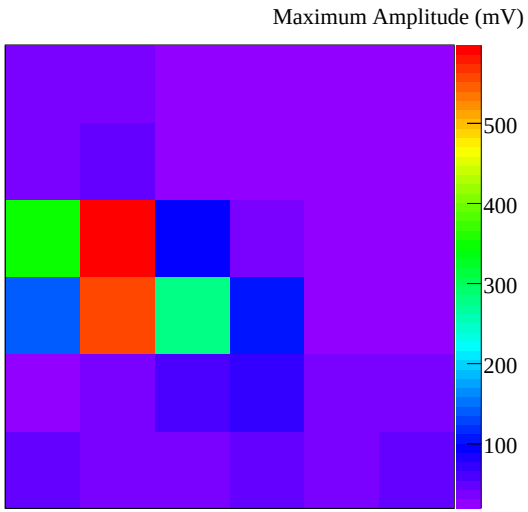


- Black:
  Open cones
- Red:
  Solid cones
- 9 mm^2 G-APDs assumed

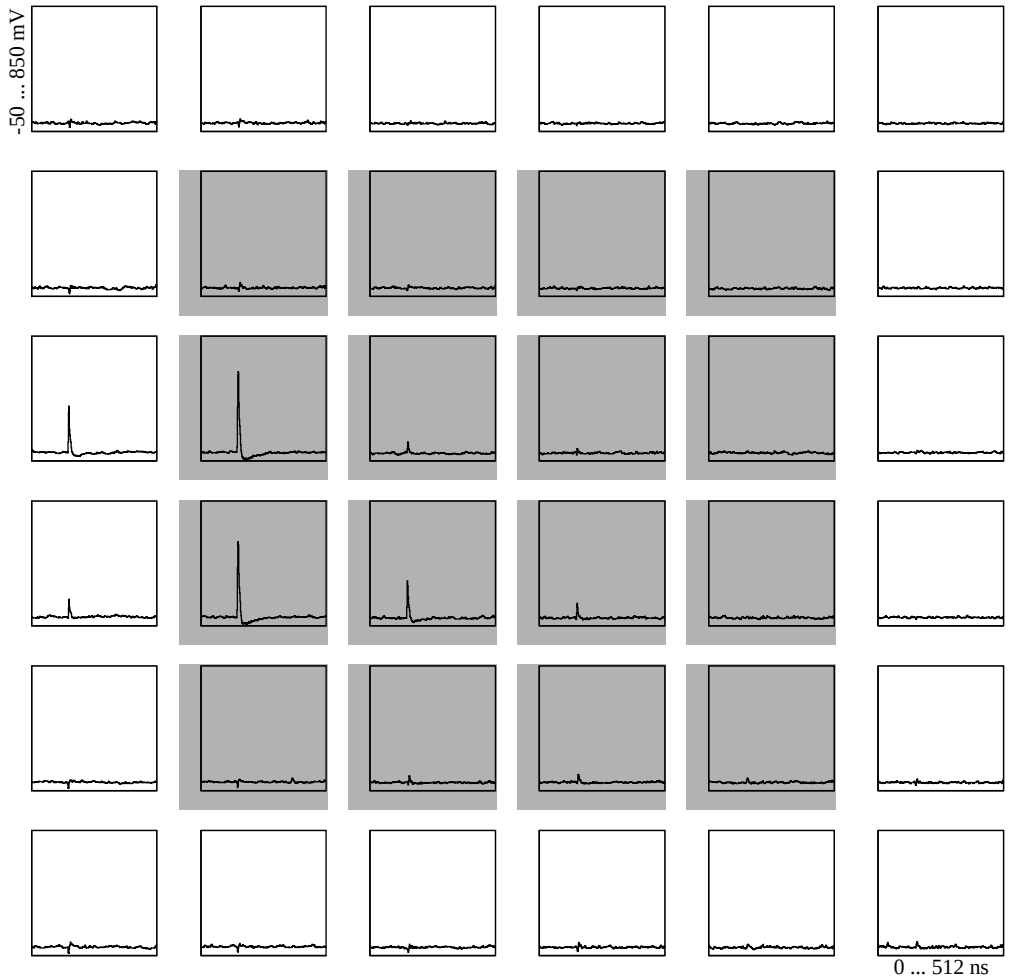
Backup: Cherenkov and NSB Signals



Backup: Recorded Cosmic Air Showers - Run# 206, Event# 8



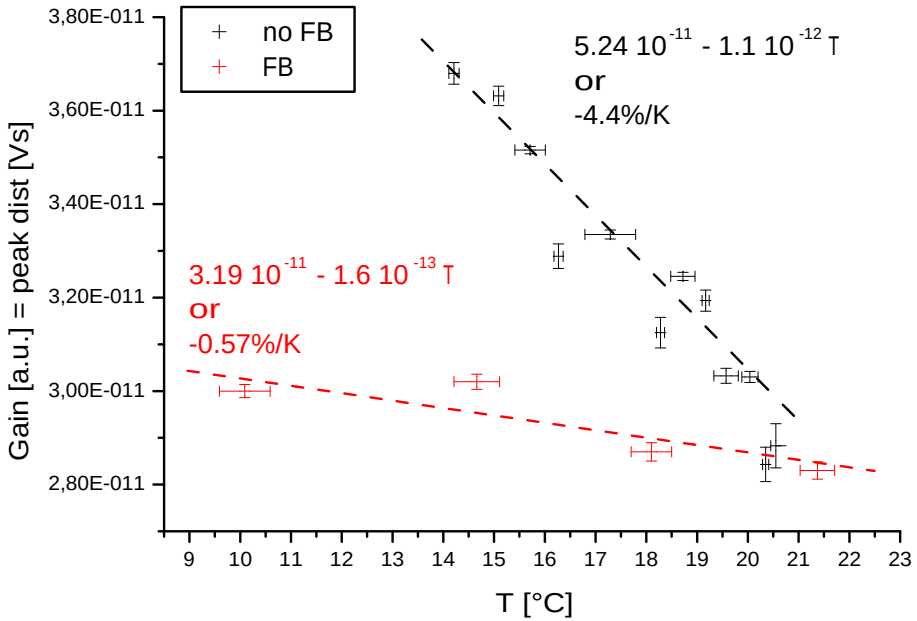
- 40 mV single pixel threshold ($\sim$ 7 p.e.)
- Majority 4 out of 16
- 1-3 kHz trigger rate per pixel
- $\sim$ 0.02 Hz total rate
- 2 GHz sampl. freq.

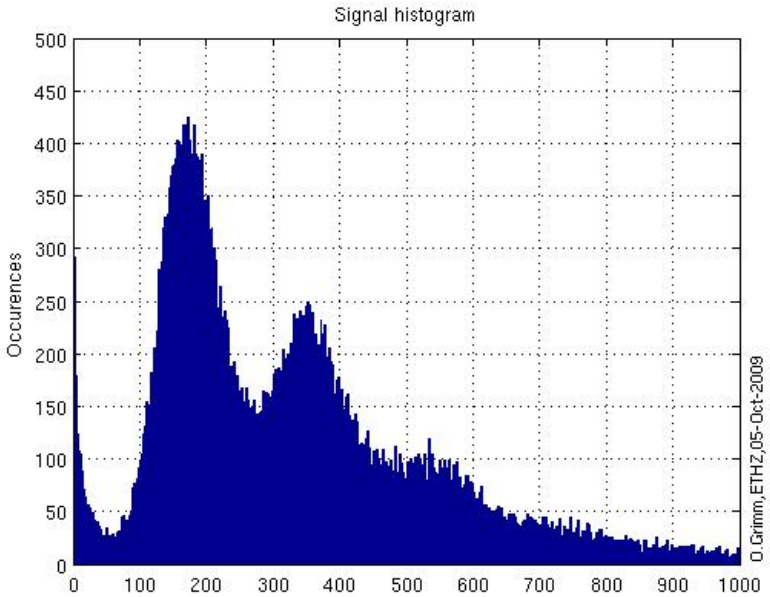


Horizontal: 0 ... 512 ns, Vertical: -50 ... 850 mV

Backup: Feedback Measurements and Dark Count Spectrum

- LED signals used for feedback system
- Gain from dark count spectrum ("singles")
- No digitization (DRS2 resolution not sufficient)





- Dark count spectrum with DRS2 digitization possible with ...
- ... additional 9x analog ampl.
- Baseline corr. (event-by-event)
- Better resolution with DRS4